WASTEWATER TREATMENT AND ENERGY RECOVERY WITH CULTIVATION OF MICROALGAE

Ignacio de Godos, Zouhayr Arbib, Enrique Lara and Frank Rogalla

FCC Aqualia
Three large scale demonstration projects started in 2011 for biofuel production from algae with ambitious, but achievable targets:

- Industrial scale of up to 10 ha
- Annual productivity: 90 Tons / ha year
www.All-gas.eu:
Partners and main objectives
All-gas project: From Wastewater to Bio-energy

Partners

- Aqualia
- Biogas Fleet vehicles
- Fraunhofer Life Cycle Assessment
- University of Southampton Lab scale Anaerobic Digestion
- HYGEAR Biogas upgrading
- BDI Lipid Extraction and Biodiesel

Coordinator
Cultivation, Harvesting, Anaerobic Digestion DEMO design
All-gas project: From Wastewater to Bio-energy

All-gas concept: Symbiosis

Raw screened WW rich in C, N and P

Microalgae

COD

Biofuels

Reusable WW

Bio-fertilizers

N, P, C

O₂

CO₂

Bacteria

FCC Aqualia
All-gas project: From Wastewater to bioenergy

1. **Screening (1mm)**
   - Raw waste water

2. **LEAR**
   - Low energy algae reactor

3. **DAFAST**
   - Algae harvesting

4. **Water Reuse**

5. **Anaerobic Digestion**
   - Algae Biomass
   - Biofertilizers

6. **Biogas**

7. **Biogas upgrading**

8. **Biomethane**

9. **Fleet Demo**
Installations:
From pilot plant to demo scale
FROM WASTEWATER TO BIOENERGY

Light & Temperature

Water

Space

No arable Land: unused salt ponds

No Freshwater

El Torno WWTP
10 000 m3/d

FROM WASTEWATER TO BIOENERGY

No arable Land: unused salt ponds

No Freshwater

El Torno WWTP
10 000 m3/d
All-gas project: From Wastewater to Bio-energy

Basic Research
2 l
2010

Pilot plant
6 x 32 m²
2012

Prototype
2 x 500 m²
2014

DEMO
2 ha
2017

All-gas gas project: From Wastewater to Bio-energy
FROM WASTEWATER TO BIOENERGY

Cultivation area

Biofuel area

5200 m² Conventional raceway

Feed pipes to raceways

5200 m² Low Energy Algae Reactor (LEAR) No. 1

Harvesting pipes to biofuel area

2750 m³ Digester - Observation tower

Dewatering building

ELAN - Anammox

Gas holder

Boiler building

Biogas pretreatment

Feed pipes to raceways

HYGEAR Pressure Swing Adsorption

Biomethane refueling station

Torch

Fraunhofer

Volkswagen

BDI
All-gas project: From Wastewater to Bio-energy

DEMO plant: Start construction March 2016

- 4 raceways of 5205 m²
- 2 X 110 m³/h DAF
- 1 X 2700 m³ Anaerobic Digestor
Innovative design
INNOVATIVE LOW ENERGY ALGAE REACTOR: LEAR

PADDLE WHEEL
Total energy efficiency:
~5% U. Florence
<17% Borowitza
~30% Weissmann

SLOW SPEED SUBMERSIBLE BOOSTER
- Mixing in many wastewater applications (carrousels)
- High propeller efficiency (mixing power/power consumption) ~ 80%
- Self cleaning properties
- Can be raised for inspection
- Gentle operation (<100 rpm)

HRAP Longitudinal section and two main cross sections
Optimization by CFD analysis

- Energy consumption determination by CFD analysis and validation with 500 m² raceways: Paddle wheel and LEAR in parallel.

EP 2875724 “Open reactor for the cultivation of microalgae”. 2013
Prototype: 1000 m² cultivation surface

Innovative Algal Pond: LEAR

Conventional vs LEAR®

- Paddlewheel: 0.5 W/m², 0.12 kw/m³ WW
- Propeller: 0.1 W/m², 0.02 W/m³ WW

80% Energy savings

Southampton, Fraunhofer, HYGEAR, BDI, FCC Aqualia
LAB TESTS:
- COAG/FLOC
- FLOTATEST

PILOT
1.5 m3/h
Comparison
- DAFAST
- SETTLER
- FILTER

PROTOTYPE
DAFAST
15 m3/h
Most relevant results
MAIN RESULTS:
6 X 32 m² ponds

**Graphs:**
- **TN (Total Nitrogen):** IN > PESB > LEAR > DAFAST
- **TP (Total Phosphorus):** IN > PESB > LEAR > DAFAST
- **COD (Chemical Oxygen Demand):** IN > Pret. > HRAP > DAF
- **HRT (Hydraulic Retention Time):** HRT 7 > HRT 5 > HRT 3 > HRT 5

**Data Points:**
- COD: IN (400 mg O₂/L) > Pret. (200 mg O₂/L) > HRAP (350 mg O₂/L) > DAF (100 mg O₂/L)
- TP: IN (12 mg/L) > PESB (10 mg/L) > LEAR (8 mg/L) > DAFAST (4 mg/L)
- HRT: HRT 7 (50 g VSS/m²d) > HRT 5 (40 g VSS/m²d) > HRT 3 (30 g VSS/m²d) > HRT 5 (20 g VSS/m²d)

**Notes:**
- IN: Initial
- Pret.: Pretreatment
- HRAP: Holographic Rapid Accurate Photometry
- DAF: Dissolved Air Flotation
Autochthonous Species: Dominance of one strain of Coelastrum sp.
PROTOTYPE Results: Cultivation and WWT

25 gVSS /m2 d = 91Ton/ha yr

Very high dilution rate (< 3 d HRT)
Pumping + cultivation + harvesting
energy ≤ 0.1 kWh/m3

Effluent fits EU directive for N + P
Biomass production and wastewater treatment

**Flow (m3/d)** | 100
---|---
**TN (ppm)** | 46.4
**TP (ppm)** | 8.3

**Flow** | 94.1
**TN** | 12.0
**TP** | 6.3
**VSS** | 263.2

**Flow** | 5 m3/d

**73% and 87 % TN and TP recovery**

**65-140 Ton/Ha yr**

**TN** | 12.0
**TP** | 1.01
**COD** | 101.2
**TSS** | 25.4
HARVESTING BY FLOTATION

DAFAST Results – Clarification and Biomass Thickening

**Chemicals**

- **Coagulation**: 20 ppm Al2O3
- **Flocculation**: 0.5 ppm Poly

**Electricity**

- **Removal efficiency**
  - P-PO4
  - TSS

<table>
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<tr>
<th>Month</th>
<th>SST effluent (ppm)</th>
<th>P-PO4</th>
<th>TSS</th>
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<tbody>
<tr>
<td>November</td>
<td>84</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>December</td>
<td>71</td>
<td>92</td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>91</td>
<td>89</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>87</td>
<td>92</td>
<td></td>
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<tr>
<td>March</td>
<td>70</td>
<td>95</td>
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<table>
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<tr>
<th>Month</th>
<th>Biomass concentration %</th>
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<tbody>
<tr>
<td>November</td>
<td>4.5</td>
</tr>
<tr>
<td>December</td>
<td>4.8</td>
</tr>
<tr>
<td>January</td>
<td>4.6</td>
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<tr>
<td>February</td>
<td>4.9</td>
</tr>
<tr>
<td>March</td>
<td>5.1</td>
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- **Total cost**: 0.01 €/m³

- **Energy consumption**: 0.05 kWh/m³
ALGAE-BACTERIA ANAEROBIC DIGESTION

LAB REACTORS
- 8X 5 L
- MESOPHILIC
- THERMOPHILIC
- CODIGESTION
- TPAD
- THERMAL HYDROLYSIS
- THERMAL HYDROLYSIS

PILOT PLANT
ALGAE DIGESTERS
2 X 600 L, 1 x 1500 L
- MESOPHILIC
- THERMOPHILIC
- AMBIENT TEMPERATURE
Energy production
Anaerobic digestion

Can we increase the biogas yield

- Similar to conventional waste activated sludge biogas production
- At ambient temperature, similar to mesophilic at twice the HRT

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<th>Range</th>
<th>L CH₄/kgVSS</th>
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<tr>
<td>Meso 35 C</td>
<td>168</td>
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<tr>
<td>Thermo 55 C</td>
<td>288</td>
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<tr>
<td>Ambient 20 C</td>
<td>147</td>
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<tr>
<td>(2 X HRT)</td>
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Range of L CH₄/kgVSS for 28 d, 21 d, and 42 d.

35 °C
55 °C
Ambient T (20-24°C)
Energy production
Enhancing the yield

Cell disruption
- Ozonization
- Thermal Hydrolysis (CAMBI)
- Enzymatic pretreat.
- Alcaline (NaOH)

CAMBI®

BMPs

Fresh

TH (lab scale) X2
All-gas ENERGY BALANCE
Energy balance of All-Gas (10 ha, 10 000 m³ d⁻¹)

- Credits for WWT, fermentation residues, and CNG in cars allow primary energy savings of ca.
  25 000 MJ d⁻¹ = 7000 kwh = 0,7 kwh / m³
Does the system provide more usable energy than it consumes? - Energy Return On Investment (EROI)

- **EROI**: Relation of primary energy supplied to primary energy used in supply process

\[
\frac{EC_{BM} + EC_{CP}}{EBM} = \frac{LHV_{BM} \cdot \rho_{BM} + EC_{CP}}{EBM} = 1.9
\]

- **EC\textsubscript{BM}**: energy content of biomethane
- **EC\textsubscript{CP}**: primary energy of the co-products fertilizer and water purification
- **EBM**: direct and indirect energy required to produce biomethane

- Algae WWT produces twice more usable energy than it consumes
  - **EROI of Corn Ethanol and Biodiesel**: 1.3
Comparison of GHG emissions of biomethane from algae to other fuels

- Biomethane from algae allows GHG savings of > than 50 %
Consumida (kWh/m³) Producida (kWh/m³)

**Conventional + CHP**

- 0.5
- 0.18

**Comparison: 10,000 m³/d plant = 10 ha surface**

- 2375 kg Algae/d
- 306 kg CH₄/d
- > 2.000.000 Km/yr

- 0.3 kwh
- 0.5 twh
- 5 kg CH₄/100 km
- 20,000 km/yr

> > 100 cars moved by bio-methane CH₄

10 cars / ha

- Compare to Bio-ethanol (Sugarcane) or Bio-diesel (Palm Oil):
- 5 cars / ha
Comparing Biofuel Production per hectare

**μAlgae (BioCH4)**

- > 10,000 kg CH4/ Ha /yr
- (5 kg CH4/100km)
- > 10 vehicles

**Sugar Bioetanol**

- 5,000 L/Ha /yr
- (5 L/100km)
- 5 vehicles

**Additional benefit in electricity savings**

0.5 - 0.2 kWh/m³ \( \rightarrow \) 0.3 kWh/m³ \( \times \) 1000 m³/d \( \times \) 365 d =

> 100,000 kWh/año

**Table:**

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<th>Country</th>
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<tr>
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<tr>
<td>UAE</td>
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<tr>
<td>España</td>
<td>19</td>
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<td>USA</td>
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Thank you for your imagination: Wastewater is Biofuel